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MORPHOLOGICAL CHARACTERIZATION OF THE BANANA INDIGENOUS CULTIVAR 'HAJI' (*MUSA X PARADISIACA*) FOR GERMPLASM DEVELOPMENT IN INDONESIA

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SUMMARY

The banana cultivar 'Haji' (*Musa x paradisiaca*)' is indigenous to the Lombok Island, Indonesia. The cultivar 'Haji' has superior characteristics like a long shelf life, which has a great potential and contribution in the breeding enhancement. A genome group classification needs conducting to further support its breeding program. The identification of 10 accessions of cultivar 'Haji' found in Lombok Island progressed based on morphology and the genome group classification. The banana cultivar 'Haji' accessions have four defining morphological characters, i.e., a predominant underlying color of the pseudostem being pink until red, a waxy appearance of the leaf's lower surface, a yellow-green-pink midrib ventral surface, and a horizontal bunch position. Among all accessions, the cultivar 'Haji' showed similarities in nine vegetative and 33 generative attributes, while the variations appeared in 14 vegetative and 15 generative traits. The genome group classification showed the banana cultivar 'Haji' had the ABB genome, and all the accessions had the defining characteristics of the ABB genome.

Keywords: Banana, indigenous cultivar, 'Haji' (*Musa x paradisiaca*), genome, cluster analysis, shelf life, morphological characters, leaf shape, bunch position

Key findings: Banana cultivar 'Haji' (*Musa x paradisiaca*) has autapomorphic characteristics that distinguish it from other cultivars in the ABB genome group. These include the predominant underlying color of the pseudostem being pink until red, a waxy appearance of the leaf's lower surface, a yellow-green-pink midrib ventral surface, and a horizontal bunch position.

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INTRODUCTION

Banana (*Musa* sp.) is an important food crop in tropical and subtropical regions worldwide. Among the fresh fruits, banana is the commodity with the highest production, volume, and trade and export values. Asia, America, and Africa are the world's leading producing regions, contributing significantly to the production and supply of bananas globally. The five Asian countries with the largest banana harvest areas are India, China, the Philippines, Vietnam, and Indonesia (Zou *et al*., 2022).

Banana fruits have numerous nutrients, viz., iron, potassium, calcium, magnesium, sodium, phosphorus, nitrogen, and fibers (Ashokkumar *et al*., 2018). Bananas also contain vitamins, such as riboflavin, folate, and vitamin C, and carotenoids like β-carotene, α-carotene, lutein, and zeaxanthin. The banana fruit has moderate protein, low fat, and high calories per 100 g of edible part, along with high levels of carbs and total sugar. With their high nutrient content, bananas are a healthy fruit advisable for consumption by individuals of all ages, particularly infants and those on diets (Hapsari and Lestari, 2016). Bananas' nutritional value contributes to their economic potential as they are a staple fruit consumed by many.

The banana's ability to grow in various environmental and climatic conditions further strengthens its economic potential (Oyeyinka and Afolayan, 2019). However, the postharvest losses due to a relatively short shelf life are some chief problems in banana production, ultimately causing economic losses (Nayab and Akhtar, 2023). Rapid ripening and susceptibility to pathogens also contribute more to postharvest losses (Murmu and Mishra, 2018; Filho *et al*., 2019).

Bananas with a longer fruit shelf life can remain stored for a longer time. The Talas bananas (*Musa x paradisiaca*), a local East Kalimantan variety, have a shelf life of around 20–24 days (Sunaryo *et al*., 2017). Another type of banana is the *Musa balbisiana* Colla (Klutuk Wulung), which has a slower ripening process and longer shelf life than the *Musa acuminata* (Dwivany *et al*., 2021a, b). The banana cultivar 'Haji' (*Musa x paradisiaca*) found in Lombok Island, Indonesia, also displayed having the longest shelf life (Gusmiati *et al*., 2018).

In the past, when Hajj pilgrims still used ships as a means of transportation to Mecca, Saudi Arabia, 'Haji' bananas often served as provisions because of their long shelf life. The banana cultivar 'Haji' fruit flesh appeared firm and not watery after 20 days of storage at ambient temperature, even though the fruit's skin started to blacken and wrinkle. The cultivar 'Haji' is one of the local bananas in the Lombok Island, West Nusa Tenggara, Indonesia. Several banana genotypes with longer shelf life have had their genome groups determined. The *M. balbisiana* Colla, Klutuk Wulung accession is in the BB genome group, whereas the Talas banana has the AAB genome (Sunaryo *et al*., 2019). However, determining the genome group of the banana cultivar 'Haji' (*Musa x paradisiaca*) is yet to be reported.

Characteristics of banana plants with the BB genome (*M. balbisiana*) include pseudostem color, which blotches slightly with a brown-purple shade. The petiole canal leaf margin curved inward. The peduncle is thinly pubescent, pedicles long. The arrangement of ovules is four rows. Bract shoulder is low, and bracts do not reflex. The bract shape is broadly ovate, and the bract apex is obtuse. The outside bract color is red-purple, and the inside is bright crimson. The color of the bract base fades continuously to red. Bract scars on the rachis are not prominent. Free tepal appearance does not corrugate below the tip. The male flower and stigma color are yellow (Sulistyaningsih *et al*., 2014; Sunaryo *et al*., 2019).

The Talas banana (genome AAB) has more morphology similar to the *M. acuminata* (genome AA) than *M. balbisiana* (genome BB). These characteristics include pseudostem color, petiole canal, peduncle, ovule arrangement, bract shoulder, bract curling, bract apex, bract scars, free tepal of a male flower, and stigma color. Meanwhile, the characters are more similar to *M. balbisiana* (BB genome) as they have long pedicels, bract shape, and color fading (Sunaryo *et al*., 2019).

Banana types are often difficult to identify because banana cultivars have various local names and synonyms in diverse languages and dialects. Therefore, it is challenging to identify a particular type based on the common name (Kundu *et al*., 2018). Different groups of bananas may refer to the same local cultivar by unlike names, giving rise to confusion and duplication in cultivation, conservation, and research activities. The banana cultivar 'Haji' on the Lombok Island has a different local name. In Bali, Indonesia, the cultivar 'Haji' has the name 'Bile' banana (Dwivany *et al*., 2020a, b). Morphological identification methods successfully identified locally cultivated types, which is a significant step in preserving and characterizing these banana cultivars (Beaton *et al*., 2023).

Identifying banana cultivars based on morphological characteristics needs carrying out to support the banana breeding program with potential traits, including those with a long shelf life (Sunaryo *et al*., 2017). Enhancing fruit shelf life is crucial for reducing postharvest losses and improving food security. The identification and classification of banana cultivars' genome groups are also essential for understanding their evolution and taxonomy. Such types of studies can help breeders to support germplasm development with desired traits, such as, disease resistance, dwarfism, parthenocarpy, and long shelf life (Elitzur *et al*., 2016; Dhivya *et al*., 2020; Martin *et al*., 2020). Therefore, the presented study aimed to verify the morphological characters and genome group classification of the banana cultivar 'Haji' (*Musa x paradisiaca*) on the Lombok Island, Indonesia.

MATERIALS AND METHODS

Plant materials

Ten accessions of cultivars 'Haji' came from West Nusa Tenggara, Indonesia. These five districts were Mataram (one accession), West Lombok (one accession), Central Lombok (one accession), North Lombok (one accession), and East Lombok (six accessions). Sampling for the out-group accession (*M. balbisiana* Colla, Klutuk Sukun) progressed in West Lombok, Indonesia (Table 1).

Morphological characterization

Morphological observations continued at the sampling location based on Sunaryo *et al*. (2019), comprising qualitative and quantitative characters in vegetative and generative organs. For organs' color observations, the Munsell color chart was the basis used.

Table 1. Location and local names of 10 accessions of 'Haji' cultivar on Lombok Island and Out-group (*M. balbisiana* Colla, Klutuk Sukun accession).

Districts	Accessions	Local Name	Elevation (m.a.s.l)
	Accessions the cultivar 'Haji'		
Mataram	Karang Anyar-Monjok Barat (M1)	Haji	17
West Lombok	Lebah Sempaga-Lebah Sempaga (LS)	Sembalun, Sambelia	332
Central Lombok	Petikus-Aik Bukak (AB)	Sembalun	486
East Lombok	Teluk-Pesanggrahan (Te1)	Bile	421
	Karang Anyar-Kembang Sari (Se)	Kelak, Bile	168
	Sapit-Sapit (Sa)	Kelak, Sembalun	660
	Kokoq Nangka-Belanting (KN)	Sambelia, Bile	50
	Pademekan-Belanting (Pa)	Sambelia, Bile	17
	Batu Tepong-Pengadangan (Pe)	Saba sembalun	686
North Lombok	Dasan Tutul-Bayan (DT)	Kelak	553
	Out-group: *M. balbisiana* Colla, Klutuk Sukun accession		
West Lombok	Montong-Meninting (KS)	Batu	17

Table 2 Morphological characters of *M. acuminata* and *M. balbisiana* banana plants for determining the genome group of the banana cultivar 'Haji (*Musa x paradisiaca*) plant (Simmonds *et al*., 1955).

No.	Morphological characters	*M. acuminata* (A genome) score 1	*M. balbisiana* (B genome) score 5
1	Pseudostem color	More or less heavily marked with brown or black blotches	Blotches very slight or absent
2	Petiole canal	Margin erect or spreading, with scarious wings below, not clasping pseudostem	Margin inclosed, not winged but clasping pseudostem
3	Peduncle	Usually downy or hairy	Glabrous
4	Pedicels	Short	Long
5	Ovules	Two regular rows in each loculus	Four irregular rows in each loculus
6	Bract shoulder	Usually high (ratio<0.28)	Usually low (ratio>0.30)
7	Bract curling	Bracts reflex and rollback after opening	Bracts do not reflex
8	Bract shape	Lanceolate or narrowly ovate, tapering sharply from the shoulder	Broadly ovate, not tapering sharply
9	Bract apex	Acute	Obtuse
10	Bract color	Red, dull purple or yellow outside; pink, dull purple or yellow inside	Distinctive brownish-purple outside; bright crimson inside
11	Color fading	Inside bract color usually fades to yellow towards the base	Inside bract color usually continuous to the base
12	Bract scars	Prominent	Scarcely prominent
13	Free tepal of male flower	Variably corrugated below tip	Rarely corrugated
14	Male flower color	Creamy white	Variably flushed with pink
15	Stigma color	Orange or rich yellow	Cream, pale yellow, or pale pink

Genome group determination

The genome group determination relied on morphological characters of the banana cultivar 'Haji' (*Musa x paradisiaca*). The study used Simmonds and Shepherd's scoring system with 15 key characters carried out on banana genotypes of *M. acuminata* (genome A) and *M. balbisiana* (genome B) (Table 2) (Singh *et al*., 2014; Sunaryo *et al*., 2019). Each banana cultivar received a score of 1, 2, 3, 4, or 5 based on their morphological traits. Score 1 indicates the cultivar is comparable and very similar to the genotype *M. acuminata*. A score of 5 implies the morphological traits are much alike to the banana genotype *M. balbisiana*. Scores 2–4 were the intermediate scores determined by evaluating the samples' likeness to *M. acuminata* or *M. balbisiana* (Sunaryo *et al*., 2019). Comparing the total score of each banana cultivar with the genetic score indication followed (Valmayor *et al*., 2000; Singh *et al*., 2014).

Data analysis

Principal component analysis (PCA) based on polymorphic morphological characters ensued on 10 accessions of banana cultivar 'Haji' and one out-group accession using the Paleontological Statistics program (Past4.08). This analysis showed the contribution of each morphological character to the diversity of the cultivar 'Haji' (*Musa x paradisiaca*) (Borborah *et al*., 2020). Clustering analysis also occurred using Past4.08 with a paired group (Unweighted Pair Group Method with Arithmetic Mean) and Euclidean similarity index.

RESULTS AND DISCUSSION

Morphological characterization

The cultivar 'Haji' has distinctive characteristics, namely, the predominant

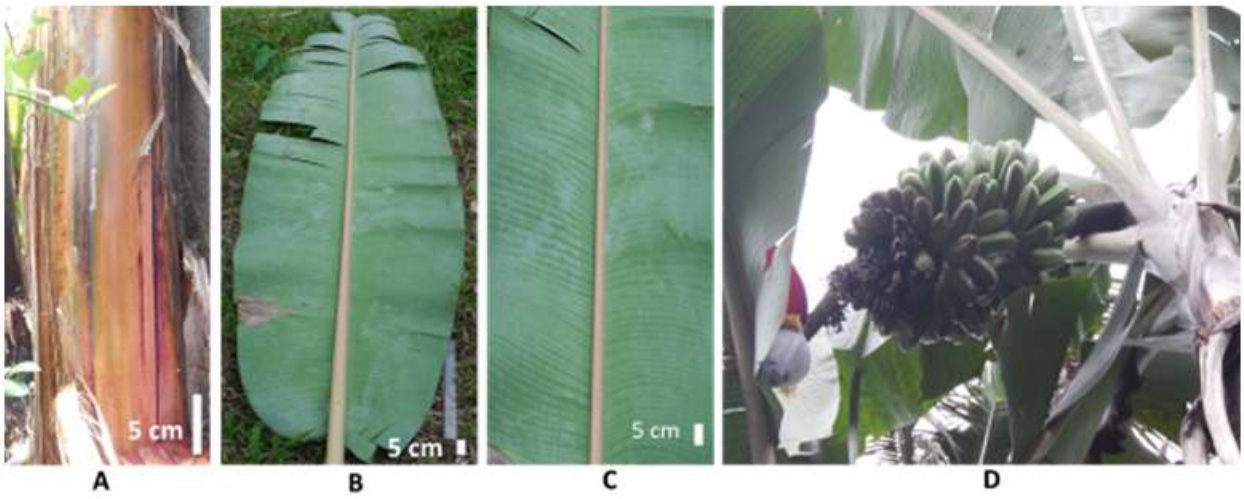

Figure 1. Typical character of the banana cultivar 'Haji' (*Musa x paradisiaca*) accessions on Lombok Island, Indonesia. A: predominant underlying color of the pseudostem, B: color of midrib ventral surface, C: appearance of leaf lower surface, D: bunch position.

underlying color of the pseudostem being pink until red, a dull (waxy) appearance of the leaf's lower surface, a yellow-green-pink midrib ventral surface, and a horizontal bunch position (Figure 1). These characteristics are autapomorphic traits that differentiate the cultivar 'Haji' from other banana cultivars found in the ABB genome group (Gusmiati *et al*., 2018). Autapomorphic characters are the typical traits inherited from specific taxa (Inta *et al*., 2023).

Other banana cultivars with the AAB genome are 'Awak,' 'Sobo Awu,' 'Bung,' 'Kates,' 'Raja Siem,' 'Ebung,' and 'Kepok Bung.' In these cultivars, the predominant underlying color of the pseudostem is green to light green. The lower surface of the leaves is quite slightly to a little waxy. The color of the midrib dorsal surface is light green, while 'Sobo Awu' is pinkish purple. The position of the fruit bunch hangs at a 45° angle, while 'Awak' has a slightly angled fruit bunch position (Gusmiati *et al*., 2018). The autapomorphic character of the 'Haji' cultivar is different from the character of this cultivar.

Based on the characterization of 71 traits, 10 accessions of the cultivar 'Haji' have 42 similar morphological and 29 varied characters (Tables 3 and 4). One of the same characteristics in all accessions of cultivar 'Haji' was a firm and yellow fruit texture when ripe (Table 3). This attribute also occurred correlated to the shelf life of banana fruits. When ripe, the fruit texture is still firm, indicating the slow decomposition process of polysaccharides and pectin in the cell walls. Loss of firmness causes the fruit to soften, which has a negative correlation with shelf life. Fruit softening is mainly due to the degradation of polysaccharides and pectin in the cell walls (Adaskaveg and Blanco-Ulate, 2023; Gardoce *et al*., 2024; Karuwal *et al*., 2024). The fruit texture interlinks with its shelf life, and the fruit's firmness can enhance its shelf life (Lusiyanto *et al*., 2021; Sridhara *et al*., 2021; Dodgson *et al*., 2022).

The 29 varied characters appeared in the vegetative (Table 3) and generative organs (Table 4). Differences in vegetative organs in pseudostem include pseudostem height, predominant underlying color pseudostem, pigmentation of the underlying pseudostem, and the sap color. The leaf organs include leaf habit, wax on leaf sheaths, blotches color, leaf blade length, and width. They also comprise petiole length, the color of the leaf upper surface, the leaf lower surface appearance and color, the wax on a leaf, the color of midrib ventral, and the leaf dorsal surface (Table 3).

Table 3. Morphological diversity of the vegetative organs of the banana cultivar 'Haji' (*Musa x paradisiaca*) accessions and out-group accession (*M. balbisiana* Colla, Klutuk Sukun).

Characters	Banana cultivar 'Haji' (*Musa x paradisiaca)*	Out-group
Leaf Habit*	Drooping (M1, LS); Intermediate (AB, Se, Te1, Pe, DT)	Erect
Pseudostem height	≥ 3 m	≥ 3 m
Pseudostem color*	Green-red (M1, LS, AB, Se, Sa, Te1, Pe, DT); Green-yellow (KN, Pa)	Moderate yellow green
Pseudostem appearance	Shiny (not waxy)	Shiny (not waxy)
Predominant underlying color of the pseudostem*	Deep pink (M1, LS, AB, Sa, Te1, Pe), light red (Se, KN, Pa), red (DT)	Moderate yellow green
Pigmentation of the underlying pseudostem*	Red (M1, LS, AB, Se, KN, Pa); deep pink (Sa); red brown (Te1, Pe), dark red (DT)	Black
Sap color*	Watery; milky (AB, DT)	Milky
Wax on leaf sheaths*	Moderately waxy (M1, LS, AB, KN, Pa, Pe, DT); very view wax (Se, Sa, Te1)	Very wax
Blotches at the petiole base*	Large blotches	Small blotches
Blotches color*	Brown-black; dark brown (KN, Te1)	Brown-black
Petiole canal leaf III	Margins curved inward	Margins curved inward
Petiole margin color*	Pink-purple to read	Brown to black
Leaf blade length*	110 – 328 cm	163 cm
Leaf blade width*	48.3 – 81.9 cm	61 cm
Petiole length*	20.8 – 71 cm	47 cm
Color of leaf upper surface*	Moderate olive green (M1, LS, Pa, Pe); grayish olive green (AB, Se); dark olive green (Sa, DT); deep yellow green (KN); olive green (Te1)	Grayish olive green
Appearance of leaf upper surface*	Shiny; dull (very little: LS)	Shiny
Color of leaf lower surface*	Moderate yellow green (M1, LS, AB); grayish yellow green (Se, Sa); light olive green (KN, Pa, Pe, DT); pale yellowish green (Te1)	Grayish yellow green
Appearance of leaf lower surface	Dull	Dull
Wax on leaf*	Moderately waxy; very little or no visible sign of wax (LS)	Very wax
Shape of leaf blade base	Both sides rounded	Both sides rounded
Color of midrib dorsal surface*	Moderate olive green (M1); strong yellow green (LS, AB, Se, Sa, Pa, Pe, DT); moderate yellow green (KN), brilliant yellow green (Te1)	Moderate yellow green
Color of midrib ventral surface*	Yellow green-pink	Moderate yellow green

M1 (Karang Anyar-Monjok Barat), LS (Lebah Sempaga-Lebah Sempaga), AB (Petikus-Aik Bukak), Se (Karang Anyar-Kembang Sari), Sa (Sapit-Sapit), Te1 (Teluk-Pesanggrahan), KN (Kokoq Nangka-Belanting), Pa (Pademekan-Belanting), Pe (Batu Tepong-Pengadangan), DT (Dasan Tutul-Bayan), KS (Klutuk Sukun). *: Different characters between the banana cultivar 'Haji' (*Musa x paradisiaca*) accessions and the out-group.

Table 4. Morphological diversity of generative organs of the banana cultivar 'Haji' (*Musa x paradisiaca*) accessions and out-group accession (*M. balbisiana* Colla, Klutuk Sukun).

Characters	Banana cultivar 'Haji' (*Musa x paradisiaca)*	Out-group
Bunch position and bunch shape	Horizontal and truncated cone shape	Hanging at angle 45° Truncated cone shape
Bunch appearance*	Compact Biseriate	Very compact Biseriate
Fruit		
Rachis position*	Falling vertically	At an angle
Rachis appearance	Neutral/male flowers on the whole stalk without persistent bracts (M1, AB, Se, Sa); neutral/male flowers and presence of withered bracts (on the whole stalk) (LS, Te1, Pe, DT); neutral flowers (one to few hands only, stalk is bare below [KN, Pa])	Bare
Male bud shape*	Ovoid	Rounded
Bract base shape*	Medium (M1, LS, AB, Se); large shoulder (Sa, KN, Pa, Te1, Pe, DT)	Large shoulder
Bract apex shape*	Intermediate; Obtuse (Sa)	Obtuse and split
Bract imbrication*	Young bracts slightly overlap	Young bracts greatly overlap
Color of the bract external face*	Dark grayish purple; dusty red (DT)	Grayish red
Color of the bract internal face*	Red (M1, LS, Sa, Te1); deep red (AB, Se, KN, Pa, Pe, DT)	Red
Color on the bract apex*	Tinted with yellow (M1); not tinted with yellow	Tinted with yellow
Bract scars on rachis*	Very prominent	Not prominent
Fading of color on bract base	Pigmentation is uniform and continues until the base	Pigmentation is uniform and continues until the base
Male bract shape* & bract lifting	Lanceolate and lifting one at a time	$0.28 < x/y < 0.30$; Lifting two or more at a time
Bract behavior before falling*	Revolute (rolling)	Not revolute (not rolling)
Wax on the bract	Very waxy	Very waxy
Male flower behavior*	Neutral/male flowers persistent (M1, LS, Se, Te1, Pe, DT); falling after the bract (AB, Sa, KN, Pa)	Falling before the bract
Compound tepal basic color*	Strong yellow (M1); yellow (LS, Sa, KN, Pa, Te1, Pe); pale brown (AB, Se, DT)	White
Compound tepal pigmentation*	Presence of pink; very view or no visible sign of pigmentation (Pa)	Very few or no visible sign of pigmentation
Lobe color of compound tepal	Strong yellow	Strong yellow
Free tepal color*	Opaque white with a yellow tint	Opaque white
Free tepal shape* and Free tepal apex development*	Oval and very developed	Rounded little or no visible of development
Free tepal apex shape*	Triangular	Thread-like
Filament color*	Yellow (M1, Sa, KN); pale yellow (LS, AB, Se, Pa, Te1, Pe, DT)	Pale yellow green
Pollen sac color*	Brown/rusty brown (M1, Se, Sa, Pe); pale yellow (LS, AB); yellow (KN, Pa, Te1); pale brown (DT)	Brown/rusty brown
Style basic color	White	White
Pigmentation on style	Without pigmentation	Without pigmentation
Style shape	Straight	Straight
Stigma color*	Yellow	Pale yellow
Ovary shape	Straight	Straight

M1 (Karang Anyar-Monjok Barat), LS (Lebah Sempaga-Lebah Sempaga), AB (Petikus-Aik Bukak), Se (Karang Anyar-Kembang Sari), Sa (Sapit-Sapit), Te1 (Teluk-Pesanggrahan), KN (Kokoq Nangka-Belanting), Pa (Pademekan-Belanting), Pe (Batu Tepong-Pengadangan), DT (Dasan Tutul-Bayan), KS (Klutuk Sukun). *: Different characters between the banana cultivar 'Haji' (*Musa x paradisiaca*) accessions and the out-group.

Table 4. (cont'd).

Characters	Banana cultivar 'Haji' (*Musa x paradisiaca*)	Out-group
Ovary basic color*	White-yellow	White
Ovary pigmentation	No visible sign of pigmentation	No visible sign of pigmentation
Dominant color of male flower*	Yellow (M1, LS, AB, Sa, KN, Pa, Te1, Pe); strong yellow (Se), pale brown (DT)	Pale yellow
Arrangement of ovules	Four rowed	Four rowed
Fruit position	Curved toward stalk	Curved toward stalk
Transverse section of fruit and fruit apex*	Slightly ridged and rounded; blunt tipped (Pa)	Slightly ridged and lengthily pointed
Immature fruit peel color*	Moderate yellow green (M1, LS, AB, Se, Sa, Te1, Pe, DT); strong yellow green (KN), moderate yellow green (Pa)	Moderate olive green
Wax on fruit peel*	Very little or no visible sign of wax	Moderate waxy
Mature fruit peel color*	Strong yellow	Yellow
Pulp color before maturity*	Pale brown (M1, LS, AB, Se, Sa, Te1); reddish yellow (KN, Pa, Pe, DT)	White
Pulp color at maturity*	Reddish yellow	White
Flesh texture	Firm	Firm
Presence of seed*	No seed	>120

M1 (Karang Anyar-Monjok Barat), LS (Lebah Sempaga-Lebah Sempaga), AB (Petikus-Aik Bukak), Se (Karang Anyar-Kembang Sari), Sa (Sapit-Sapit), Te1 (Teluk-Pesanggrahan), KN (Kokoq Nangka-Belanting), Pa (Pademekan-Belanting), Pe (Batu Tepong-Pengadangan), DT (Dasan Tutul-Bayan), KS (Klutuk Sukun). *: Different characters between the banana cultivar 'Haji' (*Musa x paradisiaca*) accessions and the out-group.

The differences in the generative organs were visible in the rachis appearance, on the bracteal covering the bract base shape, the bract apex shape, the bract's external and internal face color, and the bract apex's color. Furthermore, differences in male flowers included male flower behavior, compound tepal basic color, compound tepal pigmentation, lobe color of compound tepal, filament color, pollen sac color, and the male flower's dominant color. The difference in the fruit emerged on the pulp color before maturity (Table 4). However, 52 different morphological characters existed with the banana cultivar 'Haji' accessions and the out-group accession (*M. balbisiana* Colla, Klutuk Sukun) (Tables 3 and 4).

The banana cultivar 'Haji' (*Musa x paradisiaca*) 10 accessions revealed considerable variations in the morphological characters in this study (Tables 3 and 4). Morphological variations in the cultivar 'Haji' accessions could be due to the variations in environmental factors. Environmental factors play a crucial role in expressing the morphological qualities (Borborah *et al*., 2020). Environmental factors can cause variations in plant anatomy, morphology, and physiology (Li *et al*., 2015; Bano and Amist, 2019). The inter- and intraspecific differences can reflect limited resources and environmental stress factors. Individuals from the same species may have distinct physical traits due to environmental factors rather than the genetic variations. Plant adaptation to various environmental conditions involves physiological, morphological, and anatomical variations (Gratani, 2014).

The growing locations of the banana cultivar 'Haji' spread at altitudes of less than 400 meters above sea level (masl) and between 400–700 masl. Elevation influences both the quantity and quality of light exposure (Coll and Ameztegui, 2019). The plant organs differ in colors mainly due to the type and content of pigments, such as flavonoids, carotenoids, and chlorophyll. Physiological and biochemical changes during development are also essential in changing the composition of pigments. Environmental factors, such as light exposure, can affect the production and stability of pigments, leading to color variations (Adhikary, 2017).

The differences in color and pigmentation in the pseudostem of banana plants result from different anthocyanin content. Zhao *et al*. (2021) stated the anthocyanins are soluble phenolic compounds that are most abundant in cell vacuoles of the epidermis and hypodermis tissues. The location of anthocyanins in cells is different, which affects the color of various tissues. The formation and degradation of anthocyanins in tissues happen from influences by pH and temperature. Low temperature also decreased pseudostem height, pseudostem diameter, leaf area, and leaf number of bananas (Baysal, 2022). Plants growing in cold climates produce approximately upright leaves, but under warmer conditions, they are horizontal (Joshi *et al*., 2023).

The cultivar 'Haji' was dominant in different locations. Varied soil conditions seemed to cause morphological variations. Maseko *et al*. (2024) stated soil nutrients can affect leaf shape, growth and production, and fruit quality. Banana plants located in deep-shaded areas produce more stuntedpseu-dostems, lower leaves and suckers, smaller brunches, and delayed fruiting.

Two-dimensional PCA

From the total 71 morphological characters observed in the banana cultivar 'Haji' 10 accessions and one out-group banana accession, 42 did not show polymorphism in all accessions. The analysis results showed the five main components have an eigen value >1, including PC1, PC2, PC3, PC4, and PC5. The contribution of these five main components of morphological characters of banana accessions to the total diversity of morphological traits tested was 43.78%, 14.25%, 13.38%, 9.31%, and 8.02%, respectively. PC1 significantly contributed to the observed diversity of banana plant accessions. In PC1, the characters contributing substantially to diversity were the predominant underlying color of the pseudostem, pigmentation of the underlying pseudostem, rachis appearance, compound tepal basic color, and the dominant male flower color. Inclusion of these 29 different characteristics proceeded in the banana cultivar 'Haji' accessions. The predominant underlying color of the pseudostem was one of the typical characteristics of the cultivar 'Haji', and these differences were with the out-group accession (Klutuk Sukun).

Genome group determination

Seven out of 15 morphological characters served to determine the genome groups, which showed different scores among the cultivar 'Haji' and the out-group accessions (Table 5). These traits were pseudostem color, bract shoulder, bract curling, bract shape, bract scars, free tepal of male flower, and male flower color. The pseudostem color of the Dasan Tutul-Bayan (DT) accession was similar to the genotype *M. acuminata*, while the out-group was similar to the banana genotype *M. balbisiana*. In the cultivar 'Haji' accessions, the characteristics of bract shoulder, bract curling, and bract scars were the same as found in the genotype *M. acuminata*. Meanwhile, the out-group accession was notably similar to the genotype *M. balbisiana*. The cultivar 'Haji' accessions were evidently with different scores for the traits, viz., bract shape, free tepal male flower, and the male flower color. In these characters, and among the cultivar 'Haji' accessions, the recorded scores were 4 and 5. A score of 4 or 5 indicates that the cultivar 'Haji' accession was similar to the banana genotype *M. balbisiana.*

Summing up the scores for various characters in the banana accessions helped obtain a total score. The total score for determining the genome group in the banana cultivar 'Haji' accessions was 59 and 60, while the out-group Klutuk Sukun had a score of 71. The banana accessions with a total score of 59 were the accessions Karang Anyar-Monjok Barat (M1), Lebah Sempaga-Lebah Sempaga (LS), Petikus-Aik Bukak (AB), Teluk-Pesanggrahan (Te1), Sapit-Sapit (Sa), Pademekan-Belanting (Pa), Kokoq Nangka-Belanting (KN), Batu Tepok-Pengadangan (Pe), and Dasan Tutul-Bayan (DT). In contrast, a score of 60 appeared for the Karang Anyar-Kembang Sari accession (Se). The genome group classification of the cultivar 'Haji' (*Musa x paradisiaca*) accessions on Lombok Island

Table 5. Genome group scoring of *Musa x paradisiaca* 'Haji' accessions and out-group.

No.	Characters	Accessions										KS (Out-group)
		M1	LS	AB	Te1	Se	Sa	KN	Pa	Pe	DT	
1	Pseudostem color	3	3	3	3	3	3	3	3	3	1	4
2	Petiole canal	5	5	5	5	5	5	5	5	5	5	5
3	Peduncle	5	5	5	5	5	5	5	5	5	5	5
4	Pedicels	5	5	5	5	5	5	5	5	5	5	5
5	Ovules	5	5	5	5	5	5	5	5	5	5	5
6	Bract shoulder	1	1	1	1	1	1	1	1	1	1	5
7	Bract curling	1	1	1	1	1	1	1	1	1	1	5
8	Bract shape	4	4	4	4	5	4	4	4	4	5	5
9	Bract apex	5	5	5	5	5	5	5	5	5	5	5
10	Bract color	5	5	5	5	5	5	5	5	5	5	5
11	Color fading	5	5	5	5	5	5	5	5	5	5	4
12	Bract scars	1	1	1	1	1	1	1	1	1	1	5
13	Free tepal of male flower	5	4	4	4	4	4	5	5	4	5	5
14	Male flower color	4	5	5	5	5	5	4	4	5	5	3
15	Stigma color	5	5	5	5	5	5	5	5	5	5	5
Total score		59	59	59	59	60	59	59	59	59	59	71
Genome classification		ABB	ABB	ABB	ABB	ABB	ABB	ABB	ABB	ABB	ABB	BB

enunciated that all studied accessions have the ABB genome. According to Singh *et al*. (2014), a total score of 59–65 was prominent in the ABB genome group, while 70–75 in the BB genome group. The ABB genome indicates that the cultivar 'Haji' accessions are triploid plants with a dominant genome B, while the out-group accession (Klutuk Sukun) belonged in the BB genome group.

The B genome characters found in the 'Haji' cultivar are as follows: petiole canal (margin enclosed, not winged but clasping), peduncle (glabrous), pedicles (long), ovules (four irregular rows in each loculus), bract apex (obtuse), bract color (distinctive brownish-purple outside; bright), color fading (inside bract color usually continuous to the base), free tepal of male flower (rarely corrugated), male flower color (variably flushed with pink), and stigma color (cream, pale yellow, or pale pink). Meanwhile, the A genome characters in the 'Haji' cultivar include bract shoulder (typically high, ratio < 0.28), bract curling (bracts reflex and rollback after opening), and bract scars (prominent).

The banana cultivar 'Haji' accessions have the characteristics that distinguish themselves in the ABB genome group. These characters were the shiny (not waxy) pseudostem appearance, young bracts slightly overlap bract imbrication, purple-red bract external face, and very prominent bract scars on rachis. Other features are red bract internal face, uniform and continuous fading of color on bract base, without pigmentation in a style, straight and ovary shape, ovules with four rowed arrangements, and the fruit position curved toward the stalk (Figure 2).

In the presented study, the cultivar 'Haji' accessions have defining characteristics of the ABB group (Figure 2). The synapomorphy characters of the banana cultivar 'Haji' accessions were prevalent with the ABB genome. Synapomorphy characters' inheritance and development come from a particular taxon group (Gusmiati *et al*., 2018). Synapomorphy characters can be effective to explain the evolutionary history and classification and differentiate the various evolutionary lineages within a genus (Wei *et al*., 2017). However, a difference in one synapomorphy character in the cultivar 'Haji' accessions surfaced, which was the leaf habitus character. In the relevant study, the cultivar 'Haji' accessions were evident with the drooping, intermediate, and erect clear habitus qualities.

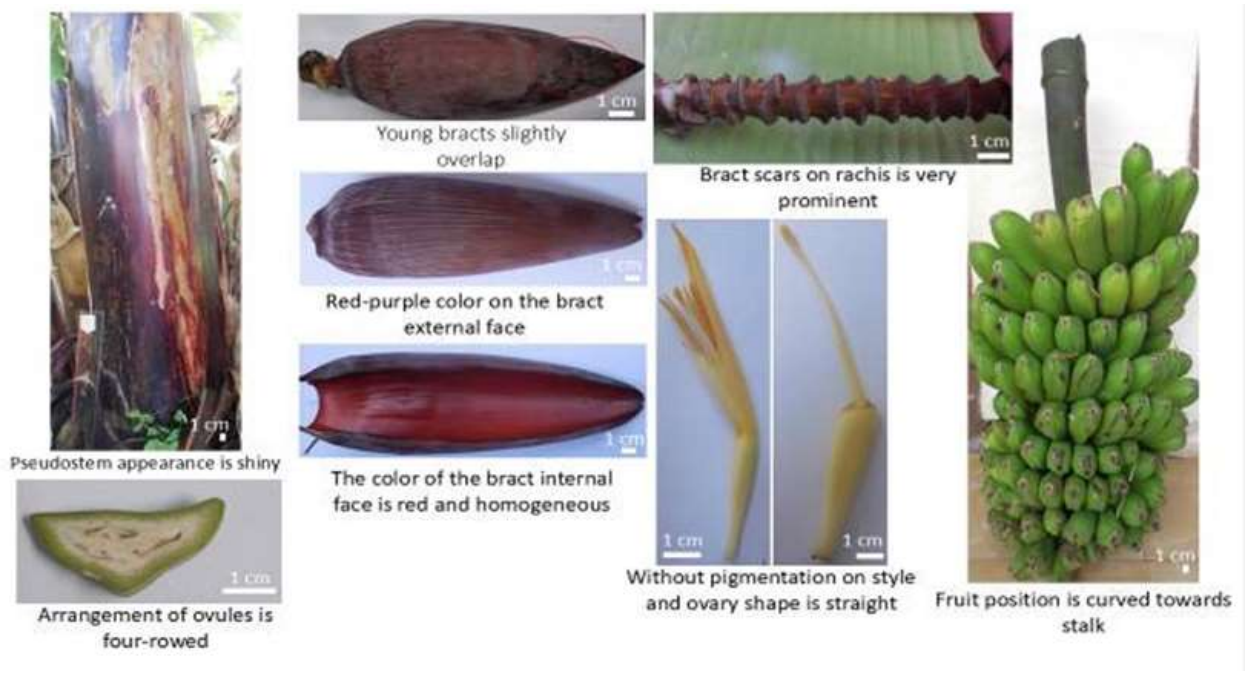

Figure 2. Characteristics of banana with the ABB genome group in the cultivar 'Haji' (*Musa x paradisiaca*).

Cluster analysis

Cluster analysis showed all studied banana accessions broke into two clades. The out-group banana accession (*M. balbisiana* Colla, Klutuk Sukun) belonged in clade 1, while the cultivar 'Haji' 10 accessions in clade 2. Clade 2 comprises six subclades, i.e., subclade A containing the accession Dasan Tutul-Bayan (DT), while subclade B contains the accession Kokoq Nangka-Belanting (KN). Subclade C consists of the accessions Sapit-Sapit (Sa) and Teluk-Pesanggrahan (Te1). Subclade D comprises the accessions Karang Anyar-Kembang sari (Se) and Karang Anyar-Monjok Barat (M1). Subclade E included the accessions Pademekan-Belanting (Pa) and Batu Tepong-Pengadangan, while subclade F has the accessions Lebah Sempaga-Lebah Sempaga (LS) and Petikus-Aik Bukak (AB) (Figure 3).

In Subclade A, the DT accession has several morphological characters that are different from other accessions. These characteristics show the predominant underlying color of the pseudostem is red, and the pigmentation of the underlying pseudostem is dark red. The color of the midrib ventral surface is strong yellow-green-pink. The color of the bract external face is dusky red. The dominant color of the male flower is pale brown. In subclade B, the KN accession has various morphological features differing from other accessions. Petiole length is 71 cm, while other accessions have petiole length ≤ 71 cm. The color of the leaf's upper surface is deep yellow-green, and the immature fruit peel color is strong yellow-green.

In subclade C, Sa and Te1 have very low wax on leaf sheaths. This character is different from other accessions. Te1 has dark brown blotches. The color of the upper surface of Te1 is olive green, while Sa is the same as DT, namely, dark olive green. The color of the leaf on the lower surface of Te1 is pale yellowish green, while Sa is the same as Se, grayish yellow-green. The color of the midrib dorsal surface of Te1 is brilliant yellow-green, which is different from the others.

Subclade D consists of Se and M1 accessions. The bract base shape of M1 and Se is medium, the same as AB and LS, while other accessions have large shoulders. Wax on leaf

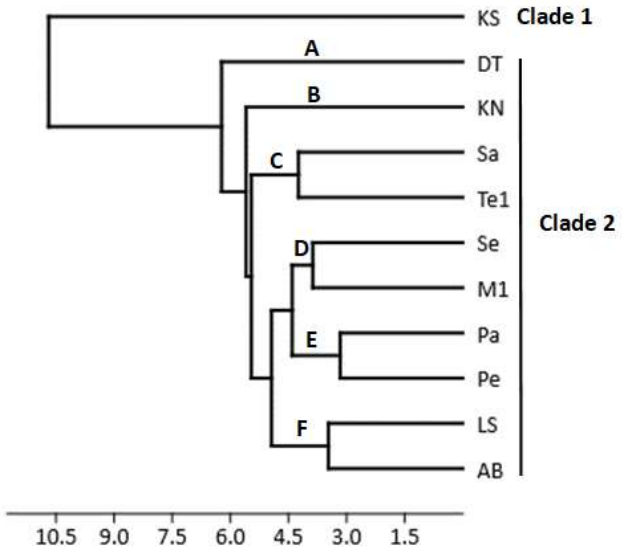

Figure 3. Kinship relationship of banana accessions based on the morphology. M1 (Karang Anyar-Monjok Barat), LS (Lebah Sempaga-Lebah Sempaga), AB (Petikus-Aik Bukak), Se (Karang Anyar-Kembang Sari), Sa (Sapit-Sapit), Te1 (Teluk-Pesanggrahan), KN (Kokoq Nangka-Belanting), Pa (Pademekan-Belanting), Pe (Batu Tepong-Pengadangan), DT (Dasan Tutul-Bayan), KS (Klutuk Sukun).

sheaths of Se is very waxy and looks the same as Sa and Te1, while M1 moderate waxy looks the same as other cultivars. The leaf blade width of M1 and Se is 81–90 cm, with other accessions being less than 81 cm. The color of the midrib dorsal surface of M1 is moderate olive green, while Se's strong yellow is the same as the LS, AB, Sa, Pa, Pe, and DT accessions. The basic color of the compound tepal on M1 is strong yellow, while Se is pale brown, the same as AB and DT. Filaments on M1 are yellow, alike with Sa and KN, while Se is the same as other 'Haji' cultivar accessions. The dominant color of the male flower in Se is strong yellow, while M1 is yellow, the same as other cultivars, except DT, which is pale brown.

Subclade E consists of Pa and Pe accessions. The leaf blade width of Pa and Pe is 71–80 cm; this is different from other accessions. The pseudostem color of Pa is green-yellow, while Pe is green-red, the same as other 'Haji' cultivar accessions. The predominant underlying color of the pseudostem in Pa is light red, but in Pe it is deep pink, the same as other accessions. Rachis appearance in Pa is neutral flowers (one to a few hands only, the stalk is bare below), the same as KN accession, and Pe is the same as LS, Te1, and DT. Compound tepal pigmentation in Pa has very few or no visible signs of pigmentation, unlike other accessions.

Subclade F contained Pa and Pe accessions. The leaf blade lengths of LS and AB accessions are more than 71 cm, but other accessions have less than 71 cm. The color of the leaf's lower surface on LS and AB is moderate yellow, which is the same as accession M1. The bract base shape on LS and AB is medium; this is the same as M1 and Se. The pollen sac color on LS and AB is pale yellow, which is different from that of other cultivars. The appearance of the leaf upper surface on LS is dull (very little), while AB is the same as other cultivars. Wax on a leaf in LS is very little or no visible sign of wax, while AB is the same as other accessions.

In the novel study, morphological characters clustering effectively grouped the banana accessions with similar characters and the same genome group. Clustering based on morphological characteristics efficiently separated the banana cultivars with identical

features and genomic groups (Wahyudi *et al*., 2020), confirming the morphological traits as taxonomic markers (Auliya *et al*., 2019). Information on banana properties and taxonomic grouping based on morphological characters can serve as a foundation for future research and further development (Gusmiati *et al*., 2018).

CONCLUSIONS

Banana cultivar 'Haji' 10 accessions, called with different local names, reached validation as 'Haji' (*Musa x paradisiaca*), and belonged to the ABB genome group. All these accessions possessed distinctive special characteristics of the cultivar 'Haji,' as follows: the predominant underlying color of the pseudostem being pink until red, a waxy appearance of the leaf's lower surface, the yellow-green-pink midrib ventral surface, and the horizontal position of the bunch. Fruit of all accessions is still firm when ripe. Clustering analysis using morphological characters also differentiated the banana cultivar 'Haji' accessions from the out-group accession (*M. balbisiana* Colla, Klutuk Sukun). This information is urgently necessary in supporting future banana breeding programs.

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